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APPLICATION OF MULTIPLE ATTRIBUTE DECISION MAKING TO THE OST PEER REVIEW PROGRAM

PHASE 2: ENHANCEMENT OF THE APPLICABILITY OF THE CURRENT TRIAGE PROCESS

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CONTENTS

EXECUTIVE SUMMARY

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For the last several years, the Office of Science and Technology (OST) of the U.S. Department of Energy (DOE) has used the joint services of the American Society of Mechanical Engineers (ASME) and the Institute for Regulatory Science (RSI) to peer review various projects and technologies that OST supports. During the initial phases of the peer review program, it became clear that the number of projects was too large for the program to review every one of them annually or even periodically. In conjunction with these activities, a study known as Triage was initiated to screen all projects and provide a numeric value for various attributes of each project. In February 2000, RSI was contacted by the OST Peer Review Coordinator with the request to continue the Triage study and bring it to a successful conclusion.

In response to this request, RSI proposed a three-phase project as follows:

1. During the first phase, the existing methodology would be evaluated and possibly expanded.

2. The second phase would consist of the application of the existing or modified methodology, along with the existing data, to rank various projects. The prerequisite for application of a modified method was that it would not require new data.

3. The third phase would consist of application of methodology that would likely pass a peer review. It was recognized that the needed data for this phase may require additional effort.

The first phase was completed in April 2000, and recommended an expansion of the existing process by the addition of the Multiple Attribute Decision Making (MADM) technique. Because MADM can use existing data, it met the requirement identified in the planning process.

This report contains the results of the second phase. Recognizing the existence of extensive information collected in support of the current Triage process, this report implements the MADM technique using the three attributes (investment, relevance, and availability) as maximum attributes to generate a single score for each project. Based upon this single score, the projects are ranked separately for each Focus Area/Cross Cutting Area.

INTRODUCTION

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For the last several years, the Office of Science and Technology (OST) of the U.S. Department of Energy (DOE) has used the joint services of the American Society of Mechanical Engineers (ASME) and the Institute for Regulatory Science (RSI) to peer review various projects and technologies that OST supports. During the initial phases of the peer review program, it became clear that the number of projects was too large for the program to review every one of them annually or even periodically.

Initially, the OST decided to require peer review for the following projects:

- Effective FY 98 all new starts
- Those that had been funded for three years and had not been peer reviewed
- Those passing through the engineering development stage (gate 4)

Subsequently, it was decided that a screening process would be useful to guide Focus Area managers and others to concentrate on those projects and those phases of projects that needed peer review for the subsequent critical decisions.

In conjunction with these activities, a study known as Triage (Wilkey et al. 1999) was initiated to screen all projects and provide a numeric value for various attributes of each project. The report by Wilkey et al. used three attributes for assessment: investment, relevancy, and availability. Furthermore, it provided numeric values for these three attributes for four Focus Areas. The authors acknowledged that one Focus Area was missing.

In February 2000, RSI was contacted by the OST Peer Review Coordinator who asked if RSI would be willing to continue the Triage study and bring it to a successful conclusion. In response to this request, RSI suggested a three-phase project as follows:

1. During the first phase, the existing methodology would be evaluated and possibly expanded.

2. The second phase would consist of the application of the existing or modified methodology, along with the existing data, to rank various projects. The prerequisite for application of a modified method was that it would not require new data.

3. The third phase would consist of application of methodology that would likely pass a peer review. It was recognized that the needed data for this phase may require additional effort.

In order to expedite the application of the Triage process, it was decided to complete the first two phases rapidly. Subsequent to the completion of the two phases, a decision would be made to embark on the third phase.

The first phase was completed in April 2000 (Straja 2000) and recommended an expansion of the existing process by the addition of the Multiple Attribute Decision Making (MADM) technique. Because MADM can use the existing data, it met the requirement identified in the planning process.

This report contains the results of the second phase. It consists of the application of the Multiple Attribute Decision Making (MADM) technique to the three attributes used by Wilkey et al. (1999). The report relies entirely upon the data provided by the Peer Review Coordinator. In addition, in order to simplify the reading of this report, those segments of the Phase I report that are used for computation are reproduced in this report.

PART I. APPLICATION OF MADM TO OST PEER REVIEW PROCESS

APPLICATION OF MADM TO THE OST PEER REVIEW PROCESS

In their report, Wilkey et al. (1999) required a number of input data from each project as follows:

1. F_n = the funding in actual $ for each FY between 1989 and 1999
2. N_1 = the number of needs addressed by the project and having priority 1
3. N_2 = the number of needs addressed by the project and having priority 2
4. N_3 = the number of needs addressed by the project and having priority 3
5. The list of needs addressed by the project and having priority 1
6. The list of needs addressed by the project and having priority 2
7. The list of needs addressed by the project and having priority 3
8. Availability date (optional)

From each Focus Area, the following input data were requested:

1. N_{1FA} = the number of needs having priority 1
2. N_{2FA} = the number of needs having priority 2
3. N_{3FA} = the number of needs having priority 3
4. The earliest and latest needs dates (optional)

In addition, the following general input data were requested:

1. CIR_n = the composite inflation rate for each year between 1989 and 1999.

Scores computation

For each project, the scores for the three attributes are computed as follows:

1. Investment:

$$F = \sum_{1989}^{1999} F_n \cdot CIR_n$$

2. Relevance:

$$R = [\frac{3N_1 + 2N_2 + N_3}{3N_{1FA} + 2N_{2FA} + N_{3FA}}] \cdot 100$$

3. Availability:

Score	= 5	available on or before earliest needs date
	= 4	available after earliest but on or before latest needs date
	= 3	indeterminate, only needs dates known
	= 2	indeterminate, only technology availability known
	= 1	indeterminate, needs dates and technology availability known

Analysis of the current triage process

The Triage presented by Wilkey et al. (1999) appears to be a multiple attribute decision making process. The authors clearly specify the three attributes (investment, relevance, and availability), but they do not specify how the solution is selected. Moreover, they do not clearly specify the nature (maximum or minimum) of the three attributes. Apparently, all three are maximum attributes.

The input data are readily available and the computations can be easily performed.

The investment attribute may be misleading. It takes into account in constant U.S. $ the amount already invested, but it does not take into account the expected future expenses. This way, projects that are nearing completion are favored (and maybe it is too late to implement any corrections) over projects that are in an incipient stage (and perhaps need review in order to identify and implement the required corrections).

The relevance attribute does not take into account the financial characteristics of different needs. All needs receive the same treatment.

The potential financial benefit that may be generated by a project is not taken into account.

Enhancement of the applicability of the current triage process

Recognizing the existence of extensive information collected in support of the current Triage process, it is reasonable to attempt to enhance its usefulness. Accordingly, the MADM technique may be used to generate a single score for a given project. It is proposed that investment, relevance, and availability as defined by Wilkey et al. (1999) be used as maximum attributes. Despite the shortcomings of the current attributes as noted above, the resulting single score will provide OST with a useful tool to enhance the applicability of the current Triage process.

PART II. MULTIPLE ATTRIBUTE DECISION MAKING

MULTIPLE ATTRIBUTE DECISION MAKING

The entropy method

Entropy has become an important concept in physics as well as in the social sciences (Capocelli and De Luca 1973; Nijkamp 1977). Additionally, entropy has a useful meaning in information theory where it is used as a measure of the expected information content of a given message. In the information theory, entropy is also used as a measure for the uncertainty of a discrete probability density function (Shannon and Weaver 1949; Jaynes 1957):

$$S(p_1,\ldots,p_n) = -k\sum_{i=1}^{n} p_i \cdot \ln(p_i)$$

Because this definition is similar to the one used in statistical mechanics, this measure of uncertainty is labeled entropy. When all probabilities are equal, the entropy reaches its maximum.

The decision matrix for a set of alternatives contains a certain amount of information. Entropy can therefore be used as a tool in attribute evaluation (Zeleny 1974; Nijkamp 1977). Entropy is particularly useful to investigate contrasts among data sets. An attribute is not very useful when all alternatives have similar values for that attribute. Furthermore, if all values are the same, that attribute should be eliminated.

The entropy of each attribute is:

$$E_j = -\frac{1}{\ln(m)}\sum_{i=1}^{m} p_{ij} \cdot \ln(p_{ij})$$

where:

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad , x_{ij} > 0 \quad \forall\, i, j$$

and x_{ij} is the numerical outcome of the ith alternative with respect to the jth attribute.

The degree of diversification of the information provided by the outcomes of attribute j is:

$$d_j = 1 - E_j$$

If the decision maker has no reason to prefer one attribute over another, the Principle of Insufficient Reason (Starr and Greenwood 1977) suggests that each one should be equally preferred. Then the best weight set that can be used is:

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j}$$

A review of other weight assessment techniques may be found in Eckenrode (1965), Hobbs (1980), Stillwell et al. (1981), Hwang and Yoon (1981), and Voogd (1983).

Technique for order preference by similarity to ideal solution

A MADM problem with m alternatives that are evaluated by n attributes may be visualized as a set of m points in an n-dimensional space. There is an ideal level of attributes for the alternative of choice (Coombs 1958; Coombs 1964). The decision maker's utility decreases monotonically when an alternative moves away from this ideal (or utopia) point (Yu 1985). Because the ideal is dependent on the current economic and technical limits and constraints, a perceived ideal is utilized to implement the choice rationale. The positive-ideal solution is defined as the hypothetical alternative with the supremum (for maximum attributes) and infimum (for minimum attributes) ratings for the m alternatives. The negative-ideal solution is defined as the hypothetical alternative with the supremum (for minimum attributes) and infimum (for maximum attributes) ratings for the m alternatives. The Technique for Order Preference by Similarity to Ideal Solution (Yoon 1980; Yoon and Hwang 1980; Hwang and Yoon 1981; Zeleny 1982; Yoon 1987; Hall 1989; Hwang et al. 1993; Yoon and Hwang 1995) is based on the fact that the selected alternative should have the shortest distance with respect to the positive-ideal solution and the longest distance with respect to the negative-ideal solution (Dasarathy 1976).

The normalized decision matrix is computed based upon the decision matrix. The vector normalization is used to compute the normalized ratings (r_{ij}) based upon the numerical outcome of the ith alternative with respect to the jth attribute (x_{ij}):

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad , \quad i = 1,\ldots,m \quad j = 1,\ldots,n$$

The weighted normalized decision matrix is computed based upon the normalized decision matrix and the weights vector, where w_j is the weight of the jth attribute:

$$v_{ij} = w_j \cdot r_{ij} \quad , \quad i = 1,\ldots,m \quad j = 1,\ldots,n$$

The positive-ideal solution A^+ and the negative-ideal solution A^- are defined with respect to the weighted normalized decision matrix as follows:

$$A^+ = \{v_1^+,\ldots,v_n^+\} = \{(\max_i v_{ij} \,|\, j \in J_1), (\min_i v_{ij} \,|\, j \in J_2) \,|\, i = 1,\ldots,m\}$$

$$A^- = \{v_1^-,\ldots,v_n^-\} = \{(\min_i v_{ij} \,|\, j \in J_1), (\max_i v_{ij} \,|\, j \in J_2) \,|\, i = 1,\ldots,m\}$$

where J_1 is the set of maximum attributes and J_2 is the set of minimum attributes. The positive-ideal solution identifies the most preferable alternative, and the negative-ideal solution identifies the least preferable alternative. The separation of each alternative from the positive-ideal solution is S_i^+ :

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2} \quad , \quad i = 1,\ldots m$$

Similarly, the separation of each alternative from the negative-ideal solution is S_i^- :

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \quad , \quad i = 1,\ldots m$$

The similarity of each alternative to the positive-ideal solution (i.e., the relative closeness of each alternative with respect to the positive-ideal solution) is S_i :

$$S_i = \frac{S_i^-}{(S_i^+ + S_i^-)} \quad , \quad i = 1,\ldots,m$$

The alternatives should be ranked in accordance to their similarities. The ranking process can be expressed through the indifference curves defined as:

$$s = \frac{S^-}{(S^+ + S^-)}$$

The indifference curve equation can be rewritten as:

$$s \cdot S^+ - (1 - s) \cdot S^- = 0$$

This equation indicates that the indifference curve is a variation of a hyperbola where the difference between two weighted distances (i.e., s and (1-s)) with respect to two focal points (i.e., the positive-ideal solution and the negative-ideal solution) is zero. A decision maker is expected to give equal preference to all alternatives located on the same indifference curve.

PART III. RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

The raw data have been received by e-mail as an EXCEL file. The file is listed in the Appendix. For each Focus Area/Cross Cut Area, the Composite Score was computed based upon the values provided for Investment, Relevance, and Availability. The Investment amount listed in Tables 1-7 has been rounded to the nearest dollar. The projects are ranked according to the Composite Score. The Composite Score is always between 0 and 1. A project has a Composite Score of 1 when it is ranked as the best project by each attribute separately. Conversely, a project has a Composite Score of 0 when it is ranked as the worst project by each attribute separately. Peer Review records indicate that several projects have already been peer reviewed by ASME/RSI.

An assessment of the Composite Score provides some interesting insights both on the applied methodology and the ranking of various projects. Because only the past expenditure is used in the Investment attribute, projects with high past expenditures usually have a high ranking. However, despite this bias, there are projects that have lower past expenditures and yet are ranked higher. For example, ID 289 in CMST is ranked lower than four projects with lower expenditures (ID 2015, ID 1514, ID 279, and ID 1547). Similarly, in INDP, ID 97 and ID 32 are ranked in front of ID 259, which has the highest expenditures. This is also valid for MWFA where project ID 2019 is ranked higher than three other projects with significantly higher expenditures (ID 2233, ID 2017, and ID 1619). Note that two of the three latter projects have already been peer reviewed. A similar situation exists for RBX with projects ranked no. 1 (ID 2178) and no. 2 (ID 2085). Both SCFA and TFA show similar patterns with a large number of projects with high past expenditures that are not ranked as the best candidates for Peer Review.

A similar situation exists for the Relevance and Availability attributes where the higher ranking projects in each one of them did not result in higher overall ranking. For TFA, the project with the highest relevancy (ID 82) is ranked as number three. Similarly, for DDFA, the project with the highest relevancy (ID 955) is ranked as number two. For INDP, the project with the highest availability (ID 259) is ranked as number three, while for RBX, the project with the highest availability (ID 2086) is ranked number five. Conversely, for CMST and INDP, the projects ranked as number one have a low availability.

The computation of a Composite Score demonstrated the value of the applied method. Clearly, the decision maker is provided with an additional tool to make the necessary decision. Due to the lack of consideration of two additional attributes, particularly the anticipated expenditure, the results of this effort are of limited value. It is necessary to recognize that the Triage process including its Composite Score suffers from some shortcomings. Accordingly, the decision maker is urged to be cautious in using these results.

Table 1. Characterization Monitoring and Sensors Technology (CMST).

Rank	Technology ID	Investment	Relevance	Availability	Composite Score
1	1999	$2,613,833	30.17	1	0.811
2	134	$1,432,566	28.05	1	0.704
3	243	$4,404,866	9.28	2	0.452
4	775	$4,407,569	6.19	1	0.398
5	308	$1,703,520	8.12	1	0.266
6	2015	$393,024	4.06	3	0.119
7	1514	$574,517	4.06	2	0.107
8	279	$739,700	3.09	3	0.105
9	1547	$465,454	2.9	3	0.094
10	289	$1,129,591	1.55	1	0.084
11	2235	$847,000	0.77	3	0.083
12	1564	$521,228	1.74	3	0.076

Table 2. Deactivation and Decommissioning Focus Area (DDFA).

Rank	Technology ID	Investment	Relevance	Availability	Composite Score
1	2330	$11,007,909	5.94	1	0.642
2	955	$777,769	61.64	1	0.398
3	2314	$76,000	12.33	1	0.097
4	2315	$56,000	6.39	1	0.049
5	2310	$100,000	0.46	1	0.004
6	2312	$77,000	0.46	1	0.002
7	2311	$54,500	0.46	1	0.000

Table 3. Industry Programs (INDP).

Rank	Technology ID	Investment	Relevance	Availability	Composite Score
1	97	$5,971,990	22.27	1	0.797
2	32	$3,513,556	22.41	1	0.732
3	259	$6,611,253	4.84	5	0.437
4	234	$3,462,192	4.98	1	0.271
5	75	$3,702,506	2.49	1	0.233
6	1543	$2,560,135	4.84	1	0.226
7	2198	$3,133,571	2.21	3	0.225
8	148	$2,534,261	3.87	1	0.199
9	278	$2,776,193	2.49	2	0.192
10	2170	$1,724,241	3.32	3	0.182
11	31	$820,381	4.98	1	0.168
12	2226	$827,302	2.77	3	0.142
13	2305	$451,620	1.66	3	0.116
14	2223	$309,796	3.32	1	0.098
15	277	$834,679	1.66	1	0.054
16	310	$731,930	1.66	1	0.049
17	2171	$814,148	0.83	1	0.041
18	2222	$231,350	1.66	1	0.033

Table 4. Mixed Waste Focus Area (MWFA).

Rank	Technology ID	Investment	Relevance	Availability	Composite Score
1	1568*	$4,267,439	5.37	4	1.000
2	1675	$1,978,649	1.15	3	0.371
3	1664*	$1,713,687	2.01	3	0.371
4	2019	$616,000	4.03	3	0.362
5	2233*	$1,861,906	1.34	4	0.360
6	2017	$1,262,561	2.88	3	0.357
7	1619*	$1,906,993	0.43	3	0.332
8	2021	$541,771	3.45	3	0.317
9	2146	$892,375	2.01	3	0.243
10	2052*	$662,498	1.53	3	0.175
11	2160	$923,258	0.77	3	0.167
12	2050*	$548,713	1.53	3	0.162
13	2056*	$266,551	1.53	3	0.139
14	2029	$685,041	1.01	3	0.139
15	2037	$485,713	1.01	3	0.111
16	1685*	$354,669	1.15	3	0.109
17	2041*	$510,700	0.86	3	0.102
18	2309	$451,688	0.96	3	0.102
19	2177	$272,025	0.86	3	0.075
20	2058	$443,375	0.58	3	0.073
21	2053*	$486,835	0.19	3	0.067
22	2163	$168,000	0.67	3	0.051
23	2047	$306,420	0.29	3	0.033
24	2129	$150,000	0.24	3	0.005

* Already Peer Reviewed by ASME

Table 5. Robotics Crosscut Program (RBX).

Rank	Technology ID	Investment	Relevance	Availability	Composite Score
1	2178	$677,697	16.67	2	0.608
2	2085	$1,317,552	5.56	2	0.560
3	2195	$225,000	13.89	3	0.420
4	2181	$600,000	9.26	3	0.399
5	2086	$708,100	5.56	5	0.377
6	2087	$502,025	9.26	4	0.374
7	2151	$356,756	2.78	2	0.084

Table 6. Subsurface Contaminants Focus Area (SCFA).

Rank	Technology ID	Investment	Relevance	Availability	Composite Score
1	10*	$9,716,202	14.18	4	0.810
2	7*	$15,855,950	7.98	2	0.655
3	1744	$5,905,390	7.52	2	0.477
4	1519*	$4,888,041	7.43	2	0.455
5	59*	$3,876,211	5.59	1	0.344
6	50*	$9,640,433	2.79	1	0.333
7	51*	$5,716,982	4.05	2	0.299
8	167*	$2,716,899	4.73	2	0.283
9	46*	$7,652,611	2.61	2	0.281
10	157	$5,648,838	2.49	2	0.228
11	162	$2,123,719	3.19	1	0.190
12	15*	$5,807,521	0.92	2	0.185
13	2158	$3,378,148	1.84	1	0.145
14	523	$3,749,949	1.23	3	0.139
15	237	$1,864,908	1.84	2	0.116
16	1773	$569,947	2.09	1	0.114
17	1772	$3,247,751	1.04	1	0.113
18	2190	$2,082,922	1.72	1	0.112
19	123*	$2,670,956	0.25	1	0.080
20	8	$1,228,069	1.29	2	0.078
21	1863	$2,315,837	0.49	2	0.075
22	2061	$2,090,700	0.55	1	0.066
23	2157	$956,736	1.04	1	0.057
24	163*	$1,660,229	0.18	2	0.052
25	2060	$270,248	0.74	1	0.033
26	2063*	$1,065,619	0.18	1	0.027
27	585	$600,507	0.18	2	0.025
28	2188	$671,869	0.31	1	0.016
29	1529	$356,000	0.4	1	0.014
30	499	$335,500	0.25	1	0.005

* Already Peer Reviewed by ASME

Table 7. Tanks Focus Area (TFA).

Rank	Technology ID	Investment	Relevance	Availability	Composite Score
1	85	$27,621,911	11.41	5	0.873
2	233*	$11,007,909	6.98	3	0.400
3	82	$5,077,205	16.64	3	0.386
4	21	$9,542,670	6.26	5	0.349
5	350	$4,626,762	5.37	3	0.201
6	20	$5,468,529	1.07	5	0.177

Table 7. (cont'd)

Rank	Technology ID	Investment	Relevance	Availability	Composite Score
7	1511	$2,283,478	5.64	4	0.155
8	2011	$4,709,131	1.07	3	0.153
9	2094	$1,417,005	5.95	3	0.150
10	1510	$2,873,042	4.7	4	0.148
11	2012	$4,209,131	1.07	3	0.137
12	2009	$2,326,570	4.38	3	0.131
13	2232	$1,619,923	4.7	5	0.125
14	2097	$2,043,905	2.86	5	0.096
15	2368	$1,745,800	2.91	3	0.090
16	1989*	$853,375	2.68	3	0.070
17	2092	$1,696,615	0.89	3	0.057
18	1985*	$1,074,518	1.88	5	0.056
19	2115	$1,219,060	1.61	3	0.054
20	2119	$1,395,019	0.54	3	0.045
21	2096	$384,050	1.7	3	0.041
22	2370	$840,000	0.94	3	0.033
23	2367	$281,000	1.07	3	0.025
24	2091	$145,675	0.36	3	0.006
25	2383	$50,000	0.18	2	0.000

* Already Peer Reviewed by ASME

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APPENDIX

Table 8. Screening metrics.

Focus Area FA	Technology ID TECH	Real Investment INVEST	Relevance REL	No. of years Funded YRS FUND	Technology Implemented IMP	Highest Gate Achieved HIGATE	Commercially Available CAVAIL	Date Implemented IMPDATE	Date Commercially Available COMDATE	Date Gate 6 Achieved G6DATE	Date Highest Gate Achieved HIDATE	Earliest Needs Date ENDATE	Latest Needs Date LNDATE	Avail-ablity based on Imple-mention Date AVAIL IMP	Avail-ablity based on Gate 4 + Achieved Date AVAIL HI	Invest-ment Rank INV RNK	Rele-vant Rank REL RNK	Funding Rank FUND RNK
CMST	134	1432565.5	28.05	5	FALSE	4	FALSE	-9999	-9999	-9999	-9999	-9999	-9999	1	1	5	2	3
CMST	1514	574516.6	4.06	2	TRUE	5	TRUE	1997	1997	-9999	-9999	-9999	-9999	2	1	9	6	11
CMST	1547	465453.7	2.9	3	FALSE	-9999	FALSE	-9999	-9999	-9999	-9999	1999	2000	3	-9999	11	9	8
CMST	1564	521227.5	1.74	3	FALSE	4	FALSE	-9999	-9999	-9999	-9999	1999	1999	3	3	10	10	8
CMST	1999	2613833	30.17	5	FALSE	5	FALSE	-9999	-9999	1998	1996	-9999	-9999	1	2	3	1	3
CMST	2015	393024.2	4.06	3	FALSE	3	FALSE	-9999	-9999	2000	-9999	1998	2000	3	-9999	12	6	8
CMST	2235	847000	0.77	1	FALSE	-9999	FALSE	-9999	-9999	-9999	-9999	1998	2000	3	-9999	7	12	12
CMST	243	4404865.5	9.28	7	TRUE	6	TRUE	1999	1994	-9999	-9999	-9999	-9999	2	1	2	3	1
CMST	279	739699.9	3.09	4	FALSE	4	FALSE	-9999	-9999	-9999	-9999	1999	2000	3	3	8	8	5
CMST	289	1129590.7	1.55	4	FALSE	2	FALSE	-9999	-9999	-9999	-9999	-9999	-9999	1	-9999	6	11	5
CMST	308	1703519.96	8.12	4	FALSE	4	FALSE	-9999	-9999	1999	-9999	-9999	-9999	1	1	4	4	5
CMST	775	4407568.5	6.19	7	FALSE	2	FALSE	-9999	-9999	-9999	-9999	-9999	-9999	1	-9999	1	5	1
DDFA	2310	100000	0.46	1	FALSE	6	TRUE	-9999	-9999	1999	1999	-9999	-9999	1	2	3	5	3
DDFA	2311	54500	0.46	1	FALSE	-9999	FALSE	-9999	-9999	-9999	-9999	-9999	-9999	1	-9999	7	5	3
DDFA	2312	77000	0.46	1	FALSE	-9999	FALSE	-9999	-9999	-9999	-9999	-9999	-9999	1	-9999	4	5	3
DDFA	2314	76000	12.33	1	FALSE	6	FALSE	-9999	-9999	1999	1999	-9999	-9999	1	2	5	2	3
DDFA	2315	56000	6.39	1	FALSE	5	TRUE	-9999	-9999	1999	1999	-9999	-9999	1	2	6	3	3
DDFA	2330	11007908.9	5.94	7	FALSE	-9999	FALSE	-9999	-9999	-9999	-9999	-9999	-9999	1	-9999	1	4	1
DDFA	955	777769.49	61.64	5	FALSE	-9999	FALSE	-9999	-9999	-9999	-9999	-9999	-9999	1	-9999	2	1	2
ESP	255	1185177.4	100	5	FALSE	5	FALSE	-9999	-9999	2000	1998	-9999	-9999	1	2	1	1	1
INDP	148	2534261.2	3.87	7	FALSE	4	FALSE	-9999	-9999	1999	1995	-9999	-9999	1	2	9	7	1
INDP	1543	2560134.59	4.84	4	FALSE	-9999	FALSE	-9999	-9999	2000	-9999	-9999	-9999	1	-9999	8	5	9
INDP	2170	1724240.94	3.32	3	FALSE	-9999	FALSE	-9999	-9999	2000	-9999	1999	2001	3	-9999	10	8	12
INDP	2171	814147.88	0.83	3	FALSE	-9999	FALSE	-9999	-9999	2000	-9999	-9999	-9999	1	-9999	14	18	12
INDP	2198	3133571	2.21	2	FALSE	-9999	FALSE	-9999	-9999	2000	-9999	1998	2024	3	-9999	6	13	14
INDP	2222	231350	1.66	2	FALSE	-9999	FALSE	-9999	-9999	2001	-9999	-9999	-9999	1	-9999	18	14	14
INDP	2223	309796	3.32	2	FALSE	-9999	FALSE	-9999	-9999	2001	-9999	-9999	-9999	1	-9999	17	8	14
INDP	2226	827301.5	2.77	2	FALSE	-9999	FALSE	-9999	-9999	2000	-9999	1999	2001	3	-9999	12	10	14
INDP	2305	451620	1.66	2	FALSE	-9999	FALSE	-9999	-9999	2002	-9999	1999	2001	3	-9999	16	14	14
INDP	234	3462192.47	4.98	6	FALSE	4	TRUE	-9999	1999	1999	1997	-9999	-9999	1	2	5	3	4
INDP	259	6611252.5	4.84	7	TRUE	6	TRUE	1997	1998	1998	1998	1999	2002	5	5	1	5	1
INDP	277	834679.01	1.66	4	FALSE	4	FALSE	-9999	-9999	1999	1998	-9999	-9999	1	2	11	14	9
INDP	278	2776193.31	2.49	6	TRUE	5	FALSE	1999	1999	1999	1995	-9999	-9999	2	2	7	11	4
INDP	31	820380.63	4.98	6	FALSE	4	FALSE	-9999	-9999	-9999	1997	-9999	-9999	1	2	13	3	4
INDP	310	731929.57	1.66	4	FALSE	-9999	FALSE	-9999	-9999	2000	-9999	-9999	-9999	1	-9999	15	14	9
INDP	32	3513555.69	22.41	6	FALSE	3	FALSE	-9999	-9999	1999	1995	-9999	-9999	1	-9999	4	1	4
INDP	75	3702505.81	2.49	6	FALSE	5	TRUE	-9999	1998	1999	1995	-9999	-9999	1	2	3	11	4
INDP	97	5971989.71	22.27	7	FALSE	4	TRUE	-9999	1998	2000	1996	-9999	-9999	1	2	2	2	1
MWFA	1568	4267439.4	5.37	7	TRUE	6	FALSE	1999	-9999	1998	1998	1998	2003	4	4	1	1	1
MWFA	1619	1906992.5	0.43	3	FALSE	4	FALSE	-9999	-9999	2000	1997	1999	1999	3	5	3	21	5
MWFA	1664	1713687	2.01	3	FALSE	4	FALSE	-9999	-9999	2001	1997	1999	2003	3	5	5	5	5
MWFA	1675	1978649	1.15	2	FALSE	5	FALSE	-9999	-9999	1999	1996	1998	2001	3	5	2	11	11
MWFA	1685	354669	1.15	2	FALSE	5	FALSE	-9999	-9999	1999	1998	1999	2004	3	5	19	11	11
MWFA	2017	1262560.6	2.88	3	FALSE	-9999	FALSE	-9999	1998	-9999	-9999	1998	2003	3	-9999	6	4	5
MWFA	2019	615999.8	4.03	4	FALSE	2	FALSE	-9999	1999	1999	1996	1999	2001	3	-9999	11	2	2
MWFA	2021	541770.5	3.45	3	FALSE	3	FALSE	-9999	-9999	-9999	1997	1999	2001	3	-9999	13	3	5
MWFA	2029	685041.3	1.01	3	FALSE	5	FALSE	-9999	-9999	-9999	1997	1999	2001	3	5	9	13	5
MWFA	2037	485712.8	1.01	3	FALSE	5	FALSE	-9999	-9999	-9999	1997	1999	2004	3	5	16	13	5
MWFA	2041	510700	0.86	2	FALSE	3	FALSE	-9999	1999	1999	1997	1998	2020	3	-9999	14	16	11
MWFA	2047	306420	0.29	2	FALSE	5	FALSE	-9999	-9999	-9999	1997	1998	1999	3	5	20	22	11
MWFA	2050	548712.5	1.53	2	FALSE	2	FALSE	-9999	-9999	-9999	1997	1998	2007	3	-9999	12	7	11
MWFA	2052	662497.5	1.53	2	FALSE	2	FALSE	-9999	-9999	-9999	1997	1998	2007	3	-9999	10	7	11
MWFA	2053	486835	0.19	2	FALSE	2	FALSE	-9999	-9999	2000	1997	-9999	2007	3	-9999	15	24	11
MWFA	2056	266550.5	1.53	1	FALSE	2	FALSE	-9999	-9999	-9999	1997	1998	2007	3	-9999	22	7	22
MWFA	2058	443375	0.58	2	FALSE	4	FALSE	-9999	1999	-9999	1997	1998	2020	3	5	18	20	11
MWFA	2129	150000	0.24	1	FALSE	-9999	FALSE	-9999	-9999	-9999	-9999	1999	2001	3	-9999	24	23	22
MWFA	2146	892375	2.01	2	FALSE	-9999	FALSE	-9999	-9999	-9999	-9999	1998	2000	3	-9999	8	5	11
MWFA	2160	923258	0.77	4	FALSE	4	TRUE	-9999	1998	1999	1997	1999	2001	3	5	7	18	2
MWFA	2163	168000	0.67	1	FALSE	-9999	FALSE	-9999	-9999	-9999	-9999	1998	2000	3	-9999	23	19	22
MWFA	2177	272025	0.86	2	FALSE	5	FALSE	-9999	-9999	-9999	-9999	1998	2006	3	3	21	16	11
MWFA	2233	1861905.7	1.34	4	TRUE	5	FALSE	1999	-9999	1999	1997	1999	2002	4	5	4	10	2
MWFA	2309	451687.5	0.96	2	FALSE	-9999	FALSE	-9999	-9999	-9999	-9999	1999	2000	3	-9999	17	15	11

Notes:

* Rankings are inversely proportional to the ranked-by value (1 is the highest rank)
* -9999 indicates missing information
* Categories for Availimp:

5 - Gate date <= earliest early Need date
4 - Gate date > earliest early Need date and Gate date <= latest late Need date
3 - No Gate date available, Need dates available
2 - Gate date available, Need dates unknown
1 - No Gate date or Need dates available

Table 8. (cont'd)

Focus Area	Technology ID	Real Investment	Relevance	No. of years Funded	Technology Implemented	Highest Gate Achieved	Commercially Available	Date Implemented	Date Commercially Available	Date Gate 6 Achieved	Date Highest Gate Achieved	Earliest Needs Date	Latest Needs Date	Avail-ablity based on Imple-mention Date	Avail-ablity based on Gate 4 + Achieved Date	Invest-ment Rank	Rele-vant Rank	Funding Rank
FA	**TECH**	**INVEST**	**REL**	**YRS FUND**	**IMP**	**HIGATE**	**CAVAIL**	**IMPDATE**	**COMDATE**	**G6DATE**	**HIDATE**	**ENDATE**	**LNDATE**	**AVAIL IMP**	**AVAIL HI**	**INV RNK**	**REL RNK**	**FUND RNK**
RBX	2085	1317552	5.56	2	TRUE	6	TRUE	1999	1998	1999	1999	-9999	-9999	2	2	1	5	1
RBX	2086	708100	5.56	2	TRUE	6	TRUE	1999	1998	1999	1999	2001	2000	5	5	2	5	1
RBX	2087	502025	9.26	2	TRUE	4	FALSE	1999	-9999	1999	1998	1999	2000	4	5	5	3	1
RBX	2151	356756	2.78	2	TRUE	4	FALSE	1998	1999	1999	1998	-9999	-9999	2	2	6	7	1
RBX	2178	677697	16.67	2	TRUE	5	FALSE	1998	-9999	1999	1998	-9999	-9999	2	2	3	1	1
RBX	2181	600000	9.26	1	FALSE	4	FALSE	-9999	-9999	2000	1998	1999	2000	3	5	4	3	6
RBX	2195	225000	13.89	1	FALSE	2	FALSE	-9999	2000	2000	1998	1999	2000	3	-9999	7	2	6
SCFA	10	9716202.3	14.18	7	TRUE	6	TRUE	1997	1997	1998	1997	-9999	2000	4	4	2	1	2
SCFA	123	2670955.7	0.25	6	FALSE	4	FALSE	-9999	-9999	-9999	1999	-9999	-9999	1	2	15	26	7
SCFA	15	5807520.5	0.92	7	TRUE	3	FALSE	1999	-9999	1999	1997	-9999	-9999	2	-9999	6	20	2
SCFA	1519	4888041	7.43	5	TRUE	-9999	TRUE	1997	1998	-9999	-9999	-9999	-9999	2	-9999	9	4	9
SCFA	1529	356000	0.4	1	FALSE	-9999	FALSE	-9999	-9999	-9999	-9999	-9999	-9999	1	-9999	28	24	30
SCFA	157	5648837.9	2.49	5	TRUE	5	TRUE	1999	-9999	1999	1998	-9999	-9999	2	2	8	11	9
SCFA	162	2123718.5	3.19	7	FALSE	-9999	FALSE	-9999	-9999	1997	-9999	-9999	-9999	1	-9999	17	8	2
SCFA	163	1660228.5	0.18	3	TRUE	3	FALSE	1999	-9999	2000	1998	-9999	-9999	2	-9999	21	28	16
SCFA	167	2716898.8	4.73	6	TRUE	4	FALSE	1999	-9999	-9999	1998	-9999	-9999	2	2	14	6	7
SCFA	1744	5905390	7.52	5	TRUE	6	TRUE	1997	-9999	1997	1997	-9999	-9999	2	2	5	3	9
SCFA	1772	3247751.4	1.04	2	FALSE	4	FALSE	-9999	-9999	-9999	1997	-9999	-9999	1	2	13	18	23
SCFA	1773	569946.8	2.09	2	FALSE	3	FALSE	-9999	-9999	-9999	1997	-9999	-9999	1	-9999	27	12	23
SCFA	1863	2315837.1	0.49	2	TRUE	5	FALSE	1997	-9999	-9999	1997	-9999	-9999	2	2	16	23	23
SCFA	2060	270248	0.74	3	FALSE	5	TRUE	-9999	-9999	1999	1997	-9999	-9999	1	2	30	21	16
SCFA	2061	2090700	0.55	3	FALSE	5	FALSE	-9999	1999	-9999	1998	-9999	-9999	1	2	18	22	16
SCFA	2063	1065619.4	0.18	3	FALSE	4	FALSE	-9999	-9999	-9999	1997	-9999	-9999	1	2	23	28	16
SCFA	2157	956735.5	1.04	2	FALSE	-9999	FALSE	-9999	-9999	-9999	-9999	-9999	-9999	1	-9999	24	18	23
SCFA	2158	3378147.5	1.84	2	FALSE	-9999	FALSE	-9999	-9999	1998	-9999	-9999	-9999	1	-9999	12	13	23
SCFA	2188	671868.5	0.31	3	FALSE	6	TRUE	-9999	1997	1997	1997	-9999	-9999	1	2	25	25	16
SCFA	2190	2082922	1.72	2	FALSE	4	FALSE	-9999	-9999	1998	-9999	-9999	-9999	1	1	19	15	23
SCFA	237	1864908.2	1.84	4	TRUE	4	TRUE	1999	1997	-9999	1998	-9999	-9999	2	2	20	13	14
SCFA	46	7652610.7	2.61	5	TRUE	4	TRUE	1998	1991	1999	1997	-9999	-9999	2	2	4	10	9
SCFA	499	335500	0.25	2	FALSE	-9999	FALSE	-9999	-9999	-9999	-9999	-9999	-9999	1	-9999	29	26	23
SCFA	50	9640433.2	2.79	7	FALSE	4	FALSE	-9999	-9999	-9999	1998	-9999	-9999	1	2	3	9	2
SCFA	51	5716982.2	4.05	8	TRUE	5	TRUE	1997	1997	1998	1997	-9999	-9999	2	2	7	7	1
SCFA	523	3749948.6	1.23	4	FALSE	4	FALSE	-9999	-9999	-9999	1995	-9999	2000	3	4	11	17	14
SCFA	585	600506.6	0.18	3	TRUE	6	TRUE	1994	-9999	1994	1994	-9999	-9999	2	2	26	28	16
SCFA	59	3876210.7	5.59	3	FALSE	4	TRUE	-9999	1996	-9999	1999	-9999	-9999	1	2	10	5	16
SCFA	7	15855950.2	7.98	7	TRUE	5	TRUE	1995	1995	-9999	1995	-9999	-9999	2	2	1	2	2
SCFA	8	1228069.1	1.29	5	TRUE	6	FALSE	1996	-9999	1996	1996	-9999	-9999	2	2	22	16	9
TFA	1510	2873041.9	4.7	4	TRUE	5	TRUE	1998	1997	1998	1997	1998	2024	4	5	9	8	6
TFA	1511	2283477.5	5.64	3	TRUE	5	TRUE	1998	1997	1998	1997	1998	2024	4	5	11	6	9
TFA	1985	1074517.5	1.88	3	TRUE	5	FALSE	1997	-9999	1998	1997	1998	2000	5	5	19	14	9
TFA	1989	853375	2.68	2	FALSE	5	FALSE	-9999	-9999	1999	1997	1998	2024	3	5	20	13	16
TFA	20	5468529	1.07	5	TRUE	6	TRUE	1996	1996	-9999	1996	1999	1999	5	5	4	17	3
TFA	2009	2326570	4.38	3	FALSE	4	FALSE	-9999	-9999	-9999	1997	2008	2008	3	5	10	10	9
TFA	2011	4709130.5	1.07	3	FALSE	5	TRUE	-9999	1997	2000	1997	1998	2024	3	5	6	17	9
TFA	2012	4209130.5	1.07	3	FALSE	5	TRUE	-9999	1997	2000	1997	1998	2024	3	5	8	17	9
TFA	2091	145675	0.36	2	FALSE	4	TRUE	-9999	1998	1999	1997	2000	2006	3	5	24	24	16
TFA	2092	1696615	0.89	2	FALSE	4	FALSE	-9999	1998	-9999	1997	2008	2006	3	5	14	22	16
TFA	2094	1417005	5.95	3	FALSE	4	FALSE	-9999	1998	-9999	1997	2002	2005	3	5	16	5	9
TFA	2096	384050	1.7	2	FALSE	-9999	FALSE	-9999	1998	-9999	-9999	1998	2020	3	-9999	22	15	16
TFA	2097	2043905	2.86	2	TRUE	5	TRUE	1997	1997	1999	1997	1998	2024	5	5	12	12	16
TFA	21	9542669.7	6.26	5	TRUE	5	TRUE	1996	1996	2006	1997	1999	2020	5	5	3	4	3
TFA	2115	1219060.1	1.61	4	FALSE	-9999	FALSE	-9999	-9999	-9999	-9999	1999	2022	3	-9999	18	16	6
TFA	2119	1395018.5	0.54	3	FALSE	-9999	FALSE	-9999	-9999	2001	-9999	1998	2000	3	-9999	17	23	9
TFA	2232	1619922.5	4.7	2	TRUE	5	TRUE	1997	1998	-9999	1998	1998	2024	5	4	15	8	16
TFA	233	11007908.9	6.98	7	FALSE	3	FALSE	-9999	-9999	-9999	1997	1998	2000	3	-9999	2	3	2
TFA	2367	281000	1.07	1	FALSE	-9999	FALSE	-9999	-9999	-9999	-9999	1998	2000	3	-9999	23	17	23
TFA	2368	1745800	2.91	2	FALSE	-9999	FALSE	-9999	-9999	-9999	-9999	1998	2001	3	-9999	13	11	16
TFA	2370	840000	0.94	1	FALSE	-9999	FALSE	-9999	-9999	-9999	-9999	1998	2024	3	-9999	21	21	23
TFA	2383	50000	0.18	1	TRUE	-9999	FALSE	1999	-9999	-9999	-9999	-9999	-9999	2	-9999	25	25	23
TFA	350	4626762.2	5.37	5	FALSE	5	FALSE	-9999	-9999	1998	1997	1998	2000	3	5	7	7	3
TFA	82	5077205.2	16.64	4	FALSE	4	FALSE	-9999	-9999	2002	1996	2001	2005	3	5	5	1	6
TFA	85	27621911.4	11.41	8	TRUE	6	TRUE	1996	1997	-9999	1997	1998	2024	5	5	1	2	1